CHARACTERIZATION OF PHASE NOISE EFFECTS IN THE PHOTODETECTION OF ULTRASHORT OPTICAL PULSES

Jennifer A. Taylor*[+], Frank Quinlan[+], Archita Hati[+], Craig Nelson[+], Shubhashish Datta[#], Abhay Joshi[#], and Scott A. Diddams[+]
***Department of Physics, University of Colorado, Boulder, CO, USA**
[+]Time and Frequency Division, NIST, Boulder, CO, USA
[#]Discovery Semiconductors, Inc., Ewing, NJ, USA

Abstract

Very-low-noise microwave signals are desirable for many state-of-the-art applications, including many types of radar and imaging systems, as well as secure communication. However, even state-of-the-art rf oscillator technology for producing signals into the tens of gigahertz range does not generate signals with low enough phase noise for these important systems to work to their full potential. A new approach for achieving microwave signals with ultra-low phase noise involves using an optical frequency divider that has as its reference a narrow-linewidth CW laser. Femtosecond laser frequency combs provide an effective and efficient way to take an ultra-stable optical frequency reference and divide the signal down into the microwave region. In order to convert optical pulses into a usable rf signal, one must use high-speed photodetection; unfortunately, excess phase noise from both technical and fundamental sources can arise in the photodetection process. In order to ultimately minimize the noise effects of the photodetector, we must first characterize some of the known sources for noise inside these devices. In this paper, we describe two of these effects – power-to-phase conversion and shot noise – within three different test diodes. The noise performance of each diode reveals the nature of the noise sources, their effect on the output signal, and what design features of the photodiode minimize these noise effects.

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14. ABSTRACT
Very-low-noise microwave signals are desirable for many state-of-the-art applications, including many types of radar and imaging systems, as well as secure communication. However, even state-of-the-art rf oscillator technology for producing signals into the tens of gigahertz range does not generate signals with low enough phase noise for these important systems to work to their full potential. A new approach for achieving microwave signals with ultra-low phase noise involves using an optical frequency divider that has as its reference a narrow-linewidth CW laser. Femtosecond laser frequency combs provide an effective and efficient way to take an ultra-stable optical frequency reference and divide the signal down into the microwave region. In order to convert optical pulses into a usable rf signal, one must use high-speed photodetection; unfortunately, excess phase noise from both technical and fundamental sources can arise in the photodetection process.

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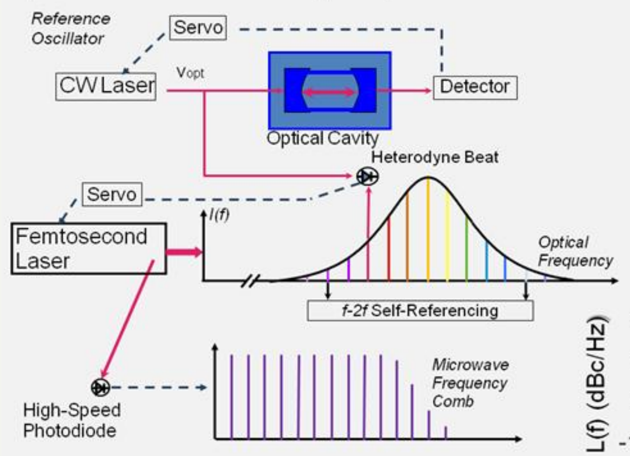
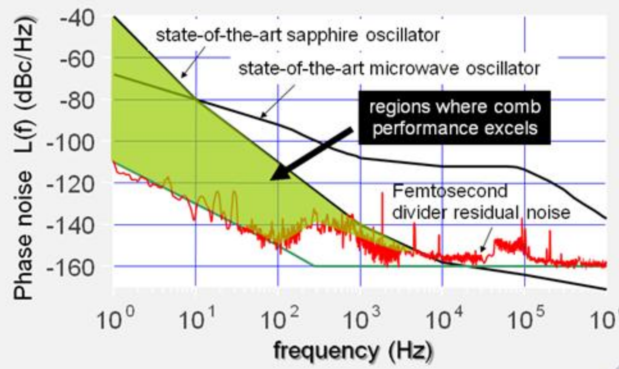
Motivation

Optical-to-Microwave Frequency Division



Optical frequency sources can provide good jitter and phase noise performance.
However, photodetectors at the link between optical and microwave can add noise that degrades those signals.

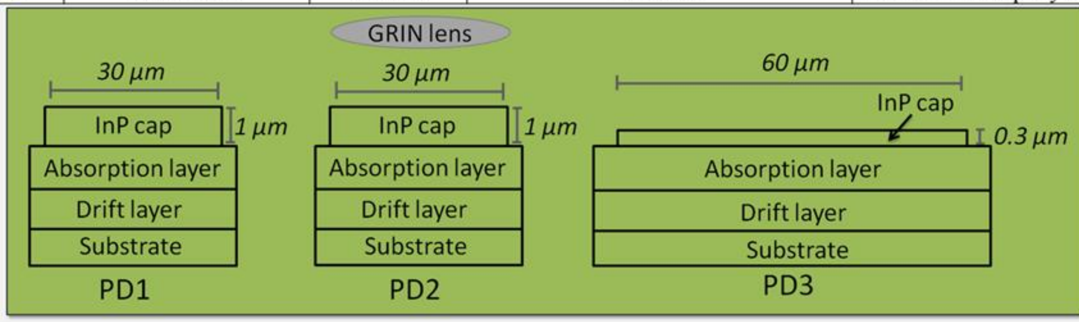


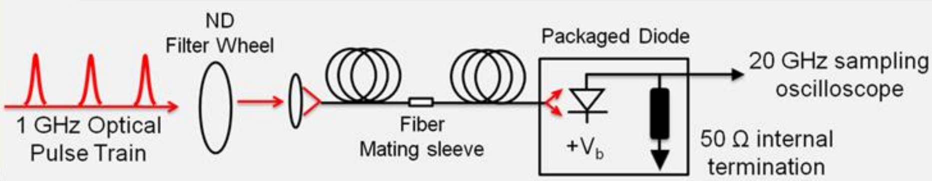
Two significant noise contributions from PD are shot noise and power-to-phase conversion.

Test Photodiodes

We consider three high-speed (>10 GHz) photo-detectors with internal termination of 50 Ω.

PD	Diode Diameter	Bandwidth	Responsivity @ 900 nm	Notable Structure
PD1	30 microns	22 GHz	0.30 A/W	SMF fiber
PD2	30 microns	22 GHz	0.26 A/W	GRIN lens coupled
PD3	60 microns	12 GHz	0.34 A/W	Thinned InP cap layer

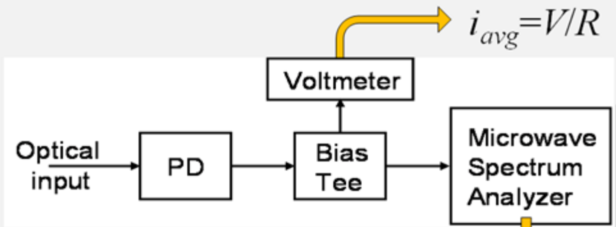


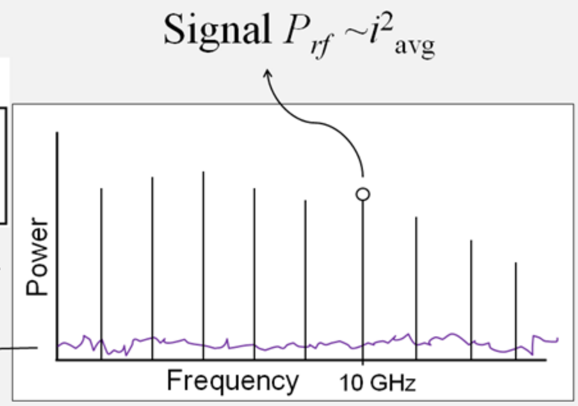


Pulse length ~1 ps; up to 25 mW is coupled into fiber.

Shot noise

Thermal (Johnson, resistive) noise and shot noise are two fundamental phenomena that occur when incoming photons are converted to an electrical signal within the semiconductor media of a photodiode. For photocurrents greater than ~1 mA, shot noise dominates over thermal noise, and this is the regime we consider here.



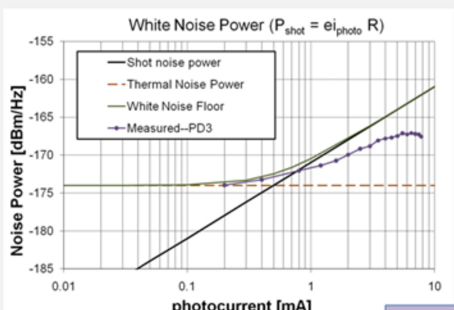


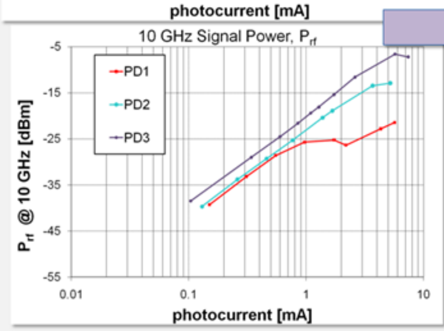
Shot noise floor in single (phase) quadrature

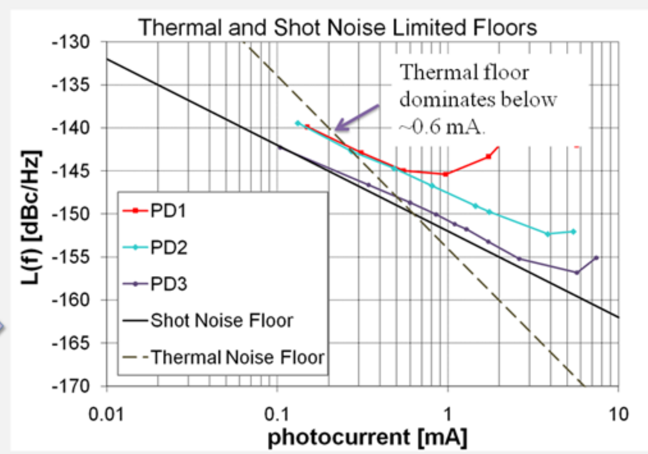
$$P_{shot} = i^2_{shot} R = e i_{avg} R$$

Shot noise as a function of photocurrent.

The fundamental shot noise and thermal noise floors at 10 GHz are pictured for these PDs [3]. The plots on the right do not include measured noise from other sources, including thermal, which is why the data fall below the thermal noise floor plot.







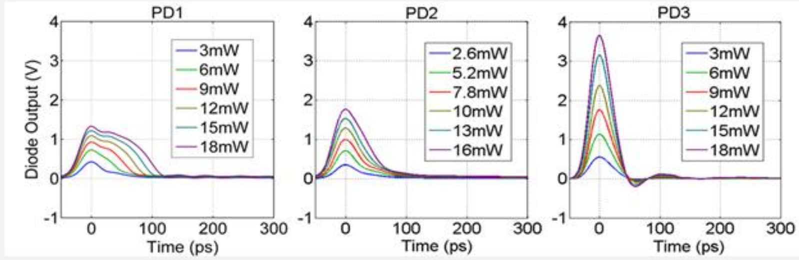
Signal increases by i^2 until saturation. Noise increases by *i*.

Shot noise power: $$L_\phi^{shot} = 10\log\left[\frac{e i_{avg} R}{P_{rf}}\right]$$

PD1 saturates at lower photocurrent than other PDs. Due to the power dependence of thermal and shot noise floors, high power handling is important for generating low noise microwave signals.

Power-to-Phase Conversion

Power to Phase conversion is a known phenomenon in photodiodes.



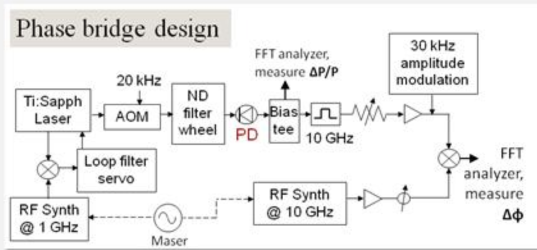
Phase Bridge Method

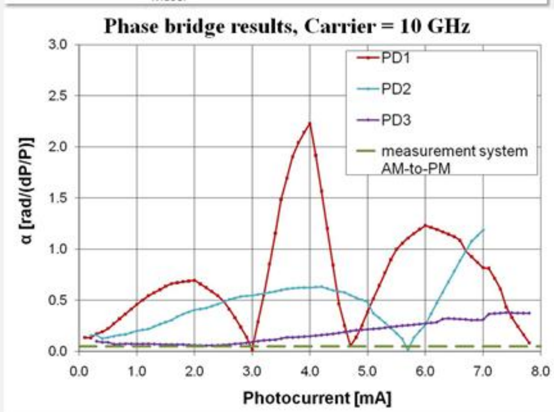
•The "Phase Bridge" method places a 20 kHz AM modulation on the incident optical light and compares the tone size (on an FFT analyzer) before and after the PD. *AM comes from AC modulation on beam*

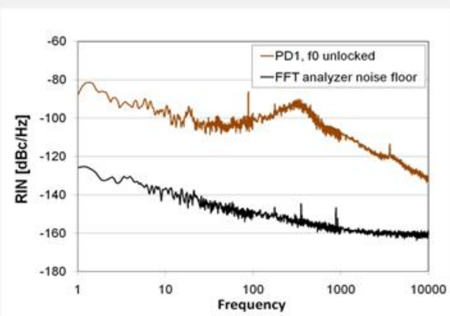
•Size of PM tone at the mixer is converted to radians using mixer gain, k_d.

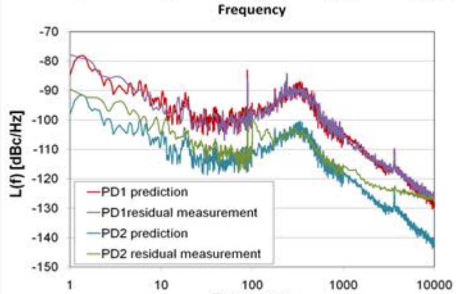
•Divide radians by the fractional (normalized) change in power [dP/P]: Power in initial AM tone (dP) divided by the optical power (P).

•PD2 in general has lower AM-to-PM conversion than PD1.









Estimate effect on AM

•Given a laser with AM noise (RIN), we can estimate the effect of AM-to-PM conversion due to photodiodes.

•The predicted contribution of AM-to-PM to the single sideband phase noise is given by $L_{RIN}(f) = RIN + 20\log(\alpha) - 3$ dB. We choose the "worst case" α for PD1 and PD2 (at 4 mA in plot above).

•To confirm, we compare to a residual phase noise measurement.

•In principle, one can operate at a null to reduce noise even further.

Conclusions

The effect of noise phenomena varies depending on the diode used and the noise of the system. You can choose a diode that exhibits the best performance in the specific application, in this case, generation of ultra-low microwave signals.

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